INVESTIGATION OF AERODYNAMIC AND RADIOMETRIC LAND SURFACE TEMPERATURES

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Introduction

The surface temperature, T_s, of a land surface measured by a radiometer, $T_{s,r}$, and the temperature "felt" by the air, T_{aero}, often differ significantly and are difficult if not impossible to define rigorously. However, recent studies conducted by the principal investigators with several land surface models suggest that this problem can be largely resolved. The main goal of this project was to use model-based and empirical studies to improve understanding and *reconcile the difference between $T_{s,r}$ and T_{aero}, while maintaining consistency within the models and with theory and data.*

The results from this effort have contributed progress towards the effective use of remotely sensed surface temperature measurements taken from an arbitrary view angle over a partial canopy cover for producing high quality sensible and latent heat flux estimates. In addition, we have developed parameterizations that are designed to improve the representation of the roughness length for heat in climate and mesoscale models. This not only provides improved representation of surface energy balance in such models, but should also facilitate the use of surface temperature measurements for validating or updating the surface temperature produced by SVATs in climate or mesoscale models.

Project Goals and Methods

The original proposal for this project included three main research objectives:

1. To investigate theoretical and conceptual differences among the formulations used for surface roughness, $T_{s,r}$ and T_{aero} among several models developed by the PI's.

2. To evaluate self-consistency and robustness of these models using field and remote sensing data, and to refine the treatments for $T_{s,r}$ and T_{aero} to provide better consistency between models, theory and data.

3. To examine the spatial scaling properties of these models and their ability to infer spatial variability of T_{aero} from spatial variations in $T_{s,r}$.

The project was conducted jointly by the PI's at Boston University, Bucknell University, the USDA, and the University of Rhode Island. In collaboration, the main accomplishments from this effort are as follows:

1. Compilation of a rich suite of data sets from field experiments for model testing, refinement and assessment.
2. Application of models to a wide range of field data taken from FIFE, SGP, BOREAS, and HAPEX. Dr. Kustas has compiled files of data from the FIFE and SGP-97 datasets to serve as a consistent dataset for inter-comparison of models. Dr. Friedl compiled data sets from HAPEX and BOREAS. Data from the Monsoon'90 experiment were also compiled and examined by Dr. Friedl.
3. Single layer and dual source models were extensively tested and refined, focusing particular attention on the representation of surface roughness lengths, aerodynamic surface temperature, and radiometric surface temperature. Specific results from these activities are discussed in the "results" section below.
4. As part of (3) above, each of the models were evaluated regarding their strengths and weaknesses. As part of this activity the range of field conditions under which model functioned well was examined.
5. Following on (4) above, the common model features that lead to good performance were identified.
6. Retrievals of remotely sensed LAI for use within the models, as well as studies of sensitivity of models to LAI, were performed.
7. Sensitivity analysis was performed to assess the sensitivity of model results to uncertainty in individual resistance terms in two-layer models.
8. Parameterizations for the roughness lengths for momentum and heat were developed that provide a more realistic representation of vegetation three-dimensional structure within SVAT models.

Results

The model of Crago (1998) was applied to 22 measurements taken at 5 sites on 10 different days in 1987 and 42 measurements taken at 2 sites on 9 different days in 1989 at FIFE. LAI at the sites ranged from 0.3 to 2.0 and canopy heights ranged from 0.19 to 0.65 m. Used in prediction mode with only a single measurement of radiometric surface temperature, the model predicted aerodynamic surface temperature with an rms error of less than 2.0 K for radiometer zenith view angles ranging from 0 to 40 degrees. Suleiman and Crago (2001) demonstrated that this is a significant improvement over the use of radiometric temperatures without the model.

The model of Price (1993) was implemented, refined, and tested to estimate LAI from visible and near infrared remotely sensed observations. Using field data from FIFE, Ju and Friedl (in preparation), show that retrieved LAI values agree well with field measurements, and that uncertainties in retrieved LAI's do not significantly affect energy balance estimates that use the remote estimates as inputs. In addition, the two-layer model described by Friedl (1995) has been refined to incorporate a new treatment for canopy transpiration (making it more general) and also to correct errors in the treatment for stability corrections and roughness length. This model was compared with the model of Norman et al. (1995), and was shown to provide comparable results.

As part of this effort, the two-layer model developed by Friedl (1995) was also used to perform a detailed analysis of the relationships among surface aero-dynamic temperature, surface radiometric temperature, surface moisture availability, wind regimes and flux simulations (see Friedl, 2002). This work was subsequently extended to provide a detailed sensitivity analysis with respect to the resistance parameterizations used in this model (Xu and Friedl, in preparation). Finally, we developed a new set of parameterizations for the surface roughness length for heat, based on recent theoretical work by Massman (1999) (Yang and Friedl, in press).

From a remote sensing perspective, a variety of work was performed that examined the conceptual/theoretical basis of directional variation in land surface temperature measurements (Li et al, 1999, Yan et al., 2001). Results from the efforts described above have been compiled in a suite of papers that are either published, in press, or in the final stages of preparation (see publication list below).

Conclusions

We now have the ability to estimate an aerodynamic surface temperature appropriate for a specific z_{0h} value with several different models, using radiometric surface temperature measurements. Further, the results from this work have provided improved understanding regarding the relationships and relative merits of one-layer versus two layer models, improved understanding of the directional dependence in land surface temperature measurements, and have also contributed to improved representation of surface temperature and sensible heat fluxes in land surface models.

No inventions were created as a result of this research.

References

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Project Publications

(i) Journal Papers

Friedl, M.A. 2002: Forward and inverse modeling of surface energy balance using land surface temperature measurements, *Remote Sensing of Environment,* Vol. 79, pp. 344-354.

Ju J.C. and M. A. Friedl. An evaluation using field data of the Price two-stream model for LAI and fractional cover estimation from remotely sensed data, in preparation for *Agricultural and forest Meteorology.*

Yang, R. and M.A. Friedl, 2002. Determination of roughness lengths for heat and momentum over Boreal forests, in press, *Boundary Layer Meteorology.*

Yan, G.J., M.A. Friedl, X.Li, J. Wang, C. Zhu, and A.H. Strahler 2001: Modeling thermal directional effects for wide-band thermal infrared measurements, *IEEE Transactions on Geoscience and Remote Sensing.* Vol 39(5), pp. 1095-1099.

Li, X., Strahler, A.H. and M.A. Friedl 1999: A conceptual model for effective directional emissivity from nonisothermal surfaces, *IEEE Transactions on Geoscience and Remote Sensing,* vol. 37(5), pp. 2508-2517.

Xu, C., and M.A. Friedl 2002. Uncertainties in aerodynamic resistance parameterizations for use in two-source land surface energy balance models, in preparation for Agricultural and Forest Meteorology, expected submission, Fall 2002.

(i) Conference Proceedings and Abstracts

Yang, R., and M.A. Friedl 2002. Determination of roughness lengths for momentum and heat over boreal forests, paper presented at the Mississippi River climate and Hydrology Conference, New Orleans, LA, May 13-17, 2002

Yang, R., and M.A. Friedl 2002. Modeling land surface radiation and energy balance over nonuniform canopies, *Eos. Trans. AGU*, 83(19), spring Meet. Suppl., Abstract B32A-04, 2002

Xu, C., and M.A. Friedl 2002. Uncertainties in aerodynamic resistance parameterizations for use in two-source land surface energy balance models, *Eos. Trans. AGU*, 83(19), spring Meet. Suppl., Abstract B32A-13, 2002

Friedl, M.A. 1999: Forward and inverse modeling of surface energy balance using land surface temperature measurements, supplement to *EOS, Transactions of the American Geophysical Union (April 27, 1999),* Boston, MA, pp. S132.

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